

Assessment of cervical trauma in posterior insults

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Paper was presented at the 20th Annual Workshop on Human Subjects for Biomechanical Research. This paper has not been screened for accuracy nor refereed by any body of scientific peers and should not be referenced in the open literature.

Abstract

The response of the cervical spine has been determined for some 100 vehicle occupants involved in a variety of real-world impacts. Special attention is paid to impacts in which the principal direction of force is directly from the rear because they constitute nearly three-quarters of that occupant population. The calculations performed include an evaluation of data from both medical and physical sources, and this combination of material enables the occupant kinematics to be derived with confidence. Consistent values are obtained for the forces in the upper and lower neck by analyses that help to reduce any possible confounding effects produced by differences in occupant physique and passenger compartment geometry. The results show how parameters of interest can be related in a general sense to certain levels of trauma, including temporary discomfort and soft tissue damage that requires several weeks of treatment.

1. Introduction

Early research into trauma from automotive crash environments concentrated on high-severity frontal impacts that involved injury to the head and chest, and the first legislative activity on human tolerance levels addressed this particular concern.^[1-7] (Superscripted numbers in brackets denote references at the end of the paper.) Reasons for this emphasis included the widespread occurrence of frontal impacts in real-world accident statistics and the life-threatening consequences of trauma to such major body regions. Over the past decade or so, there has been an increase in the amount of attention paid to side impacts.^[8-12]

The corresponding development of anthropomorphic test devices (ATDs), or “dummies”, to model human response to insults has played an important part in all of these studies. Examples of dummies used in frontal impacts are the Alderson Part572, Hybrid II, and Hybrid III, to name a few, while devices such as SID, Eurosid, and Biosid have been used for side impacts. In addition to these studies on frontal and side impacts, insults in the vertical direction have been investigated in both aviation^[13, 14] and naval^[15, 16] environments.

Although relatively little effort to date has been expended on rear impacts and rollovers, the experience gained from the above activity provides a good background. The research described in this paper continues the ideas presented elsewhere,^[17-19] and much of the technical details are given therein. A number of approximations and assumptions are inherent in any modeling effort, including those outlined above, and the basis for accepting such simplifications lies in the fact that reasonable results are obtained. Even in the well-documented area of high-severity frontal impacts, there are problems in calibrating the response of an ATD and this constraint is borne in mind for this research also.

The analysis performed throughout this research places particular emphasis on occupant kinematics and injury mechanisms, leading to a determination of the forces experienced within the cervical spine. The good agreement between the calculated results and the available clinical indicators validates the techniques employed and suggests that they can be applied with the same success to other cases.

2. Methodology

The reader is referred to previous work^[17-19] for a full description of the technique employed in this study to model occupant kinematics with the Crash Victim Simulation (CVS) program.^[20-31] The accuracy and reliability of CVS have been seen in a wide variety of real-world accidents,^[17-19, 32-42] from which it has been found that CVS produces good absolute results and even better comparative results. Calculations for the occupants involved here lie in the latter domain and they lend themselves well to CVS because any simplifications will tend to be applied systematically to all cases.

The key element in this study is the capture of both clinical and engineering data over a period of two years to form a real-world population of close to 100 vehicle occupants. The medical records of most interest within these data include reports by emergency room physicians, neurosurgeons, orthopedic surgeons, and other specialists; range-of-motion studies and similar physical examinations; and radiography results from röntgenograms, computerized tomography scans, and magnetic resonance imaging. The relevant aspects of the physical data encompass measurements of the damage profile and of the passenger compartment, inspection of the accident scene, photographs of the damaged vehicles, property damage estimates, police reports, and witness statements.

Although these data have been gathered from a number of different sources, they have one thing in common — all of them have passed through the offices of Edge Associates in Silver Spring, Maryland. Edge Associates is a small multidisciplinary company that conducts research into aspects of interest to the scientific, technical, and educational communities. The company has expertise in areas of physics, engineering, and computing, and it undertakes a range of studies for government, schools, and private business. The collaboration between Edge Associates and members of the medical professions is a major factor in the collection, interpretation, and analysis of the data discussed in this work.

The distribution of impact conditions for the abovementioned real-world occupant population is summarized in Table 2.1, which contains three categories for the type of restraint use: no belt at all, a two-point lap belt (in some rear seat occupants), and a three-point lap-shoulder belt. Occupants in the last of these categories are referred to as being fully restrained. The impact severities have been categorized by a range of speeds rather than by a single value because this generates better statistics and also reduces the difficulties inherent in estimating low-severity insults. The peak-to-peak speeds v_{p-p} ^[17-19] in the table are typified by values of (say) 2 or 3 miles per hour (mph), 4 to 6 mph, and 7 to 10 mph for the V1, V2, and V3 ranges, respectively. The choice of these demarcation lines is related to how the speeds were determined; they are not arbitrary. The prevalence of direct rear impacts (i.e. those at six o'clock) in the table is somewhat to be expected when the only body region being considered is the cervical spine.

The measure of injury adopted for this research is the maximum absolute value of the anterior-posterior (A-P) force within both the upper and lower neck, denoted by $F(UN)$ and $F(LN)$, respectively. This choice is based on the fact that the A-P forces are known to be greater than those in the lateral and inferior-superior directions for previous studies of rear and side impacts.^[17-19] For all the occupants studied, the A-P forces provided the most relevant indicator for comparison with human tolerance data.^[43-47]

3. Results

Values of $F(UN)$ and $F(LN)$ were calculated for each group of occupants located in the rear impact column of Table 2.1, and then a simple statistical analysis was performed to find the mean, standard deviation σ , minimum, and maximum for each impact condition. The results of this procedure are tabulated for the following combinations: fully-restrained occupants subjected to different impact severities (Table 3.1), occupants in the V1 speed range with different types of restraint use (Table 3.2), and occupants in the V2 speed range with different types of restraint use (Table 3.3).

The first two lines of Tables 3.2(a) and (b) are based on just one occupant and therefore need to be treated with some caution, and this also applies to the second line in Tables 3.3(a) and (b). The primary motivation for including such limited data is to provide an indication of what can happen, without asserting that it necessarily occurs in all other similar cases.

Table 2.1

Distribution of occupants subjected to a given combination of impact severity, type of restraint use, and impact angle

direction of insult (o'clock)												
1	2	3	4	5	6	7	8	9	10	11	12	Σ
V1 none 2-pt 3-pt	- - -	- - -	- - -	- - -	1 1 29	- - -	- - -	- - -	- - -	- - -	1 - -	2 1 29
V2 none 2-pt 3-pt	- - -	- - -	- - 1	- - 4	3 1 28	2 - 3	- - -	- - 1	1 - 1	- - 1	- - 3	6 1 43
V3 none 2-pt 3-pt	- - -	- - -	- - -	- - 2	- - 4	- - -	- - -	- - -	- - 1	- - 1	- - -	- - 8
Σ none 2-pt 3-pt	- - -	- - 1	- - 1	- - 6	4 2 61	2 - 3	- - -	- - 1	1 - 2	- - 2	1 - 3	8 2 80

0 1 0 1 6 67 5 0 1 3 2 4 90

Table 3.1

(a) Forces (in pounds) within the upper neck in fully-restrained occupants

speed	mean	σ	minimum	maximum
V1	52	14	24	78
V2	93	9	77	115
V3	223	44	174	286

(b) Forces (in pounds) within the lower neck in fully-restrained occupants

speed	mean	σ	minimum	maximum
V1	59	16	28	90
V2	105	10	88	129
V3	255	52	198	330

Table 3.2

(a) Forces (in pounds) within the upper neck for the V1 speed range

belt	mean	σ	minimum	maximum
none	18	-	-	-
2-pt	30	-	-	-
3-pt	52	14	24	78

(b) Forces (in pounds) within the lower neck for the V1 speed range

belt	mean	σ	minimum	maximum
none	20	-	-	-
2-pt	34	-	-	-
3-pt	59	16	28	90

Table 3.3

(a) Forces (in pounds) within the upper neck for the V2 speed range

belt	mean	σ	minimum	maximum
none	88	10	74	98
2-pt	82	-	-	-
3-pt	93	9	77	115

(b) Forces (in pounds) within the lower neck for the V2 speed range

belt	mean	σ	minimum	maximum
none	101	12	84	113
2-pt	93	-	-	-
3-pt	105	10	88	129

4. Discussion

The values in Table 3.1(a) show a clear progression in the forces within the upper neck with increasing impact severity when occupants are restrained fully. There is a distinct pattern in these $F(UN)$ and almost no overlap between the different speed ranges. In medical terms, a value of $F(UN) \approx 50$ pounds for V1 has been found to correspond to no discomfort at all or to minimal discomfort lasting only a matter of hours. There is no indication of any pain or injury at this impact severity. The increase of $F(UN)$ to about 90 pounds for V2 is sometimes associated with slight discomfort that dissipates quickly over a few days at most, and again no injury is indicated. It is only when $F(UN)$ reaches the values for V3 that temporary discomfort is often, but by no means always, replaced by pain.

The above generalizations cannot be expected to apply to every individual occupant because other factors such as age, gender, stature, and previous medical history have not been included at this stage. The interpretation of medical information usually enables these factors to be taken into account, and an example of this is seen in the instances where there is no discomfort at the V3 impact severity. Conversely, at this same V3 level there are rare occurrences of soft tissue damage requiring treatment over several weeks. There are limited data that suggest similar exceptions can also be found at the V1 and V2 levels, but these anomalies contain unusual circumstances that often involve subjective observations.

Human tolerance levels^[43, 44] for the neck are measured at the occipital condyles under static conditions, whereas $F(UN)$ are dynamic values associated with the C1 and C2 vertebrae.^[17] Any discrepancy introduced by these differences is likely to be small, and comparisons of $F(UN)$ with such tolerances can be made on at least a semi-quantitative basis, which is beyond the level required for the general approach adopted here. Consequently, the results derived in this study can be considered to be consistent with the nominal tolerance of 200 pounds as a threshold of discomfort in the A-P direction.

The limited information in Table 3.2(a) suggests that no discomfort is produced for any type of seat belt use at V1, and the slight increase in values of $F(UN)$ with restraint use cannot be viewed as significant. The forces in Table 3.3(a) are very similar for all types of belt use at V2 and none of these low values for $F(UN)$ can be expected to have any pain associated with them. The results contained in Tables 3.1(b), 3.2(b), and 3.3(b) are presented for illustration purposes only because they apply to the C6 and C7 vertebrae^[17] and therefore cannot be assessed against any human tolerances. However, it should be noted that values for $F(LN)$ in the tables are about 10 percent greater than the corresponding values for $F(UN)$, a finding that agrees well with the ratio of $F(LN)$ to $F(UN)$ seen elsewhere.^[17-19]

The probability of injury for each impact severity can be summarized in descriptive terms such as negligible, minimal, and slight for V1, V2, and V3, respectively, although it may not always be possible to distinguish between these categories when certain anomalous circumstances are present.

5. Conclusions

This research constitutes a systematic study into the relationship between cervical trauma and impact severity for real-world vehicle occupants. Demarcations are seen between (a) no discomfort for the V1 severity level and possible discomfort for V2, (b) possible discomfort for V2 and possible pain for the lower part of V3, and (c) possible pain for the lower part of V3 and possible soft tissue damage for the upper part of V3 and beyond. The general description of these boundaries is intentional because some variation is to be expected when so many different passenger compartment geometries and occupant characteristics are involved. The type of restraint use for V1 and V2 has little or no effect on the probability of injury because all probabilities at these impact severities are low.

The findings reported here are an important contribution to the identification of trauma in rear impacts at low severity. As in any modeling of occupant response to insults, the use of physical devices or computer simulations inevitably introduces some assumptions and approximations. However, the comparative nature of this study reduces these simplifications because relative values are not as dependent on unknown calibration data as absolute values. Some refinements might be possible when such calibration data are available, but this is not likely to occur in the immediate future because low impact severities are not a priority when much work remains to be done at higher impact severities.

Acknowledgments

It is a pleasure, once again, for the author to record his appreciation and gratitude to Ed Mulligan of Edge Associates, Silver Spring, Maryland, for his support and encouragement of this research.

"Now unto him that is able to keep you from falling, and to present you faultless before the presence of his glory with exceeding joy, to the only wise God our Saviour, be glory and majesty, dominion and power, both now and ever. Amen." ^[48]

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DISCUSSION

PAPER: **Assessment of Cervical Trauma in Posterior Impacts**

PRESENTER: Dr. Saami Shaibani

QUESTION: Dr. Levine, Wayne State University

Two front seat occupants, they would both be exposed and subject to the same acceleration, that would be a good comparison group for you?

ANSWER: I've done that. In fact, some of these data do include that and it is very interesting. One with a belt and one without a belt and that's a great benchmark. That's only true for a six o'clock impact though, Bob. If we have a five o'clock impact, then that's five o'clock to the driver but it is seven o'clock with respect to the passengers because of the antisymmetry involved if they are both wearing belts.

Q: Guy Nusholtz, Chrysler

How are you planning to address things which cannot be addressed by CVS, things like height and weight which are addressed by CVS? Small changes in vehicle structure may be the dominant factor which changes the injury profile and yet that can't be addressed by the approach. How are you going to distill that or determine those?

A: Good question, Guy and you're right. We are beneath the level of resolution of CVS. All I'm saying is we use CVS to try and give us a perspective we don't otherwise have. One of the beauties of CVS is that you can keep asking yourself "What if". If I move the seat backward or forward. If I put the belt on or off. If I try and do a full size test with all the instrumentation and so on. That's going to get very expensive and very extravagant. So the only reason for using CVS is it's quick and dirty. What kind of ballpark are we in? Is all the simplification and assumption and approximation exercise so gross that we can't see through the noise and, at this stage, I don't know but I think that on some of the data, we are getting reasonable values, that it does agree with our common sense and if that's the case, those can then become benchmarks to try and pick discrepancies and, as Paul pointed out, that no matter what your vehicle has got, no matter what type of structure you have in your vehicle and two people inside the vehicle are exposed to the same insult and two different things happen, then I think CVS may be one of the tools to say, "why on earth is that a discrepancy?", and I've already picked up on that. Fortunately, most vehicles are driven in this country with just the one occupant. I couldn't give you a percentage. I'm sure there are people here who can. In those cases, where there are two occupants, sometimes you do get incredible discrepancies and CVS, at least qualitatively, is picking up on those.

Q: Just because you have two occupants in the same vehicle doesn't mean both occupants are subject to the same forces. That only occurs if the vehicle happens to move straight in a one dimensional manner. If it rolls, pinches or moves in any other way, you're going to have different inputs to the different occupants.

A: That's correct, Guy, but this study is very narrowly defined for a six o'clock direct rig input and so again, it is not going to be exact, but as Paul pointed out, it is going to be comparable. I've already mentioned that the five o'clock impact is different if both occupants are seated, then that is equivalent to a seven o'clock impact for the passenger if it is a five o'clock impact for the driver.